June 1998

Avatars á la Snow Crash

Jan M. Allbeck
University of Pennsylvania

Norman I. Badler
University of Pennsylvania, badler@seas.upenn.edu

Avatars á la Snow Crash

Abstract
We analyzed Neal Stephenson's novel *Snow Crash* for all references to avatars. This analysis is documented here, including a comparison of the Snow Crash avatars to the current state of real-time virtual human research. The avatar characteristics discussed include appearance, clothing and attachments, ethnicity, locomotion, body actions, forms of communication, and emotion and personality.

Comments
Copyright 1998 IEEE. Reprinted from *Proceedings of Computer Animation, 98*, pages 19-24. Publisher URL: http://dx.doi.org/10.1109/CA.1998.681903

Avatars á la Snow Crash

Jan M. Allbeck and Norman I. Badler
Center for Human Modeling and Simulation
University of Pennsylvania
200 S. 33rd St., Philadelphia, PA 19104-6389
allbeck@gradient.cis.upenn.edu

Abstract

We analyzed Neal Stephenson's novel Snow Crash *for all references to avatars. This analysis is documented here, including a comparison of the* Snow Crash *avatars to the current state of real-time virtual human research. The avatar characteristics discussed include appearance, clothing and attachments, ethnicity, locomotion, body actions, forms of communication, and emotion and personality.*

1. Introduction

A literary image of Virtual Environments populated by virtual beings is offered by the Neal Stephenson novel *Snow Crash*. Stephenson defines a *Metaverse* that is mostly populated by real people who go there by donning an avatar that represents them in that space. The Metaverse is a virtual reality world envisioned as a large cyber-planet. It contains homes, corporate headquarters, nightclubs, and virtually every other type of building found in reality and some that are not. Individuals from around the world materialize on this cyber-planet, and are represented there by avatars. There are also totally synthetic characters, of greater or lesser capability and complexity, who interact with real characters in the Metaverse as if they were simply avatars for real people. Given the overall tone of the novel, these avatars and human-mimicking synthetic characters appear simply to be science fiction.

Over lunch in early 1997, one of the authors (Badler) and David Farber were discussing the upcoming Virtual Humans 2 conference. Farber remarked that an analysis of state of the art relative to the Metaverse in *Snow Crash* might form an interesting subject for a Panel. We reread *Snow Crash* for all references to the avatars that inhabit it. The analysis was the basis of Badler's Panel presentation at Virtual Humans 2 in June 1997. This analysis is documented and expanded here, including a comparison of the *Snow Crash* avatars to the current state of real-time virtual humans. The avatar characteristics discussed include appearance, clothing and attachments, ethnicity, locomotion, body actions, forms of communication, and emotions and personality. The overall question addressed by this paper is thus: Given the avatar descriptions in *Snow Crash*, how far away from that virtual reality is the graphics field as of 1998?

2. Avatar Characteristics

2.1. Appearance

In the novel, the avatars' appearances are as diverse as the people they represent. One area of diversification is the image quality. There are well rendered, realistic looking avatars, there are avatars called black-and-whites, and there are avatars of various gradations in between. The rendered avatars can have all of the physical attributes of real human beings, including: age, gender, aesthetics, ethnicity, height, and weight (see Appendix A). However, these avatars do always take human form. The book describes gorillas, dragons, and "wild-looking abstracts, tornadoes of gyrating light" (page 41) to name a few. The amount of detail found in the rendered avatars is also quite diverse. For example, page 198 contains a description of a very detailed avatar: "It is an honest representation, with no effort made to hide the early suggestions of crow's feet at the corners of her big black eyes. Her glossy hair is so well resolved that Hiro can see individual strands refracting the light into tiny rainbows." In contrast, page 37 describes a female avatar's eyelashes as "rendered as solid ebony chips."

The quality of an avatar's appearance stems from the software used to create it and the quality of the computer being used to login to the Metaverse. In reality, there are public terminals that people can use to login to the Metaverse. When people use these terminals to enter the Metaverse, they are represented by avatars called black-and-whites. These black-and-whites are best described in passage from page 41: "Talking to a black-and-white on the

Street is like talking to a person who has his face stuck in a Xerox machine, repeatedly pounding the copy button, while you stand by the output tray pulling the sheets out one at a time and looking at them." Black-and-whites are a very low-resolution version of what the user looks like in reality. Furthermore, unlike the well-rendered avatars, which have 3D sound, black-and-whites possess very poor sound. In the Metaverse, black-and-whites are considered "scum of the earth."

In general, the art of graphical human forms is advanced enough to create the sorts of models described in *Snow Crash*, because such detail can be designed off-line and then displayed during live interactions. Body, face, skin, and muscle models have been created by many groups, including [32, 21, 4, 54, 60, 13].

2.2. Clothing and Attachments

Though it is not required, most avatars in the Metaverse don some sort of clothing. A black-and-white's clothing emulates what the user is wearing in reality. It appears that the clothing for a rendered avatar is created when the avatar is created and does not change unless new software is written. The actual clothing varies as widely as the avatars' innate appearances do. The "hero" of the story, Hiro, wears a black leather kimono, but there are also business suits, golfing duds, and uniforms among others (see Appendix B). An important feature of the clothing found in the Metaverse is pockets. Many of the avatars in the novel carry hypercards in their pockets. Hypercards are little cards, which can contain written data, photographs, audio clips, and video clips. They are an important form of communication in the novel. The avatars also carry objects that will not fit into their pockets. For example, Hiro's black leather kimono is accessorized with swords, which he often uses to do battle.

It appears that the present state of modeling avatar clothes is adequate for the *Snow Crash* figures, e.g. [14, 17].

2.3. Ethnicity

Hiro's avatar wears a kimono in part because of his ethnicity. He is part Asian and part African-American. Although the Metaverse probably contains avatars of many nationalities and ethnic groups, Stephenson only explicitly mentions a few: Aleutians, Americans, Asians, Italians, Japanese, and Vietnamese. In addition to these actual ethnic groups a couple of virtual ethnic groups inhabit the Metaverse. One group could be labeled exotic and contains the avatars of non-human form like the "tornadoes of gyrating light." The other group consists of Brandys and Clints. These are generic, off-the-shelf avatars. Brandy and Clint software is widely available in reality and comes in different forms. As with all avatar software, the cheaper versions have fewer options and lower quality. Unlike custom made avatars, Brandys and Clints have a very limited number of facial expressions (see Appendix C).

Individuals can be crafted in advance with various software systems such as Poser [50] or VRML [23]. Skin color has been studied by Kalra [28]. The behavior differences that accrue from ethnicity are just receiving attention from our research group and others.

2.4. Locomotion

Regardless of their appearance or ethnicity, avatars in the Metaverse must move around. There are various forms of locomotion found in *Snow Crash* (see Appendix D). The novel does not explicitly discuss the realism of these movements, but it does use verbs of varying styles. For example, avatars do not just walk around. They also, maneuver carefully, run, saunter, and charge at people. This diversification of movements and the fact that Stephenson does not mention a lack of realism in the movements indicates that the movements probably appear natural and realistic. Stephenson does, however, mention that not everyone knows how to properly maneuver his or her avatar. "He looks like a guy who's just goggled into the Metaverse for the first time and doesn't know how to move around" (page 203).

Real-time avatar locomotion has been rather extensively studied. There are several examples for gait, walking, and arbitrary stepping [42, 8, 20, 29, 51, 34].

2.5. Body Action

Stephenson describes a wide variety of body actions (see Appendix E). These range from things as simplistic as "gesturing to the wall" or "sitting motionless" or "waving toward the next quadrant" to more intricate actions such as "pulling a hypercard out of her pocket" or "snapping his fingers" or "sword fighting." The body actions found in the novel include positional changes such as moving the legs, arms, head, face, torso, and many combinations of these. These body actions appear to be natural and realistic: in fact, the novel indicates that some people's avatars have the same mannerisms as the people they are representing. Also, unnatural movements would remind the visitors to the Metaverse that they are just in a play world. "People hate to be reminded of this" (page 102).

Body motion is crucial to avatar behavior and is accordingly well studied: [7, 12, 11, 59, 21, 37, 57, 9, 24, 36, 4, 3, 22, 30, 31, 52, 15, 48, 49, 58, 43].

2.6. Forms of Communication

In the Metaverse, as in reality, people use various forms of communication. Among them are language, attention, facial expressions, and body language. The spoken communication in the novel ranges from “mumbling” to “ear-splitting screeching,” and the quality of the sounds depend on the quality of the avatars and the quality of the equipment producing them. Black-and-whites possess rather poor quality sound, but well-rendered avatars have 3D sound that is of high enough quality to produce crisp accents (page 43) and to distinguish people by their voices (page 65). The references to attention can be termed explicit or affective. Explicit attentions found in the novel include “looking at weapons”, “gazing,” “staring,” and “listening.” Affective attentions include “eyeing him warily,” “glaring,” and “giving dirty looks” (see Appendix F). As related in the following passage from page 64, Stephenson feels that facial expressions and body language are the most important forms of communication: “They come here [The Black Sun] to talk turkey with suits from around the world, and they consider it just as good as a face-to-face. They more or less ignore what is being said–a lot gets lost in the translation, after all. They pay attention to the facial expressions and body language of the people they are talking to. And that’s how they know what’s going on inside a person’s head–by condensing fact from the vapor of nuance.”

Attention control is being studied by Chopra [16] Extensive literature on facial animation exists: [44, 39, 2, 46, 47, 45, 35]. Efforts on other gestural communication include [40, 11, 10, 38, 15, 33].

2.7. Facial Expressions, Emotion, and Personality

Facial expressions seem to be particularly important, and again can be classified as either explicit or affective. Explicit expressions include: fluttering eyelashes, pursed lips, flicking of the eyes, and the corners of the mouth curling downward. Affective expressions include raising the eyebrows expectantly, dubious looks, stunned looks, and expressionless looks (see Appendix G). On the well-rendered avatars, facial expressions can be quite fine grained. For example, a smile is not just a smile. There are “satisfied grins,” “grins of recognition,” “indulgent smiles,” “stifled grins,” and “huge relaxed grins” just to name a few (see Appendix H). Avatars’ personalities come from the people they represent, and can be as diverse as those people. In contrast, the personalities of the daemons (autonomous actors) seem to be very limited. The Librarian is the most prevalent daemon mentioned. His mood and personality as indicated by his dialog and expressions appear constant and limited. He often “raises his eyebrows expectantly” (pages 107, 205, 208, 215), but does little else. Some emotions and personalities found in the novel are listed in Appendix G.

Emergent work on emotion and its manifestation in faces and bodies include [48, 49, 5, 6, 1, 53].

3. Other Observations

The Metaverse does have some limitations as far as its avatars are concerned. Although at any one time approximately 120 million people can be found on the Street, there is no collision detection among them. In fact, when there is a large number people, the computer draws ghostly avatars so that a person can see where he or she is going. The Black Sun, however, does provide collision detection and opaque avatars. It can accomplish this because there is only a limited number of avatars admitted to the Black Sun at any one time. Another limitation of the Metaverse is the lack of tactile feedback. Avatars in the Metaverse bow instead of shaking hands, because shaking hands would ruin the illusion of reality. Also, all of the avatars in the Metaverse are equally strong. In order to contribute to the illusion of reality, avatars should possess a strength attribute. Furthermore, the Metaverse is governed by a standards organization that has established a few rules. One, avatars on the Street cannot be taller than the people they represent in reality. Two, one person’s avatar cannot exist in two places at the same time. And three, avatars cannot materialize out of nowhere. There are ports, which are designated places where avatars can materialize. It is also possible to materialize into homes in the Metaverse. These restrictions are in place in order to maintain the realism of the Metaverse.

Some of the issues here are addressed by efficient collision detection algorithms [25], navigation issues [41, 51], and shared environments [55, 43].

4. Conclusions

Real-time avatars exist now, but the degree of realism is dependent on input sensing technologies. The input or control methods used in *Snow Crash* are not very clear (it is, after all, science fiction!), but appear to be based on active laser scanning. It is not obvious what the rest of the user interface is like – whether the participant has to act out the avatar’s motions, operate some tactile or position sensitive input device, describe them (speech understanding with emotional analysis?), or just imagine them. One passage seems to indicate that facial expressions are tracked (page 420). It does not preclude the use of face tracking, but another passage describes an avatar as having a limited number of facial expressions (page 37). The same is true of body motions. In a passage from page 103 it seems as though Hiro had been performing the same actions as his avatar, but in a later passage (page 420) his avatar goes slack while he is busy in reality. Currently, face input (from unmarked faces) is nearly real-time [18, 19], and whole body motion capture from video is not far off [27]. Current laser scanning systems are not close to real-time.

Some body and facial motions can be previously captured and replayed in context. This requires some parameterization so they can be executed in the current context and blended or coarticulated for more natural flow and appearance. Triggering the correct action is, again, unspecified. The complexity of game console controls with even a small complement of buttons would lead one to postulate some more effective input mechanism than just joystick manipulation or button pushes for combinatorial selection. (Textual instructions via speech input are one possible expressive option [56].) Given the complex motions currently embedded in some sport simulation games, however, it is clearly possible to endow an avatar with a considerable action vocabulary provided that there is an appropriate mechanism to select (and control) the desired one.

Realistic appearance, clothing, attachments, and ethnicity can be created in advance for an avatar. The reactions of the avatar to a given situation are presumably dependent on the live participant, thereby minimizing the computational intelligence required by the avatar. For example, the wide range of subtle facial expressions is obtained by some direct input means rather than by any synthetic procedure that monitors the conversation and figures out the emotional content! It is likely that some of the "little" movements that surround an avatar might be automatically generated: e.g., attention (facing), searching, watching, and maybe small locomotor movements to maintain personal space and body orientation toward subject. Spatialized sound is important to localize events and other avatars in the Metaverse and may be used to control some automated search and attention functionality. The processing that accompanies sensory inputs and the decision-making which precipitates action (and hence appearance) go well beyond current avatars though some efforts are emerging [26, 16].

The autonomous actors who interact with the avatars in *Snow Crash* need more work. Notably, they appear to lack emotional involvement and hence facial expressions and body affect. Actually, there are only a hand full of autonomous actors mentioned. There are daemons in the Black Sun that serve drinks and run errands, but they are not well described. There are also gorilla bouncer daemons whose only interactions with avatars are shoving them around and throwing them out. The Graveyard daemons work in the underground tunnels. They are simply programmed to follow instructions and burn any avatar remains found in the tunnels. The geisha is limited to massaging backs and being dismissed. There are Vietnamese people working in rice paddies and running around a village, but they are only really there as scenery. The book also describes a receptionist actor. She is limited to asking questions and ushering people to their desired locations. She does not understand irony and is never impressed by any one. The best described autonomous actor is the Librarian. He appears to be the only autonomous actor capable of changing his facial expressions. Even so, he seems to be limited to raising his eyebrows expectantly, having his eyes glance upward as if he is thinking about something, and staring off into the distance as he clears his throat dramatically. At one point he also shakes his head minutely. He is portrayed as a dignified intellectual, and described as pleasant, cheerful, and eager. The only indication of emotional involvement is during a passage in which Hiro tells a joke. The Librarian does not understand the joke and when it is explained to him the novel indicates he is not very amused (page 108).

In summary, we believe that communications bandwidth and graphics rendering speed are the primary current limitations to *Snow Crash* scene complexity and number of avatars. Other aspects of *Snow Crash* avatar design, motion, and appearance offer no challenges that are unmet in the research literature. The major gaps seem to lie in the control transformation from the user's desires to the avatar's actions and in the modification of an animated action based on the attitude, personality, and reactions of the live participant.

5. Acknowledgments

This research is partially supported by ONR through Univ. of Houston K-5-55043/3916-1552793; DARPA SBMDA-97-2951001 through the Franklin Institute; ARO DURIP DAAH04-95-1-0023; National Institute of Standards and Technology 60 NANB6D0149; NSF IRI95-04372; and the Ashton Fellowship Foundation.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation nor any other sponsoring organization.

A. Appearance

See http://www.cis.upenn.edu/˜allbeck/appear.html

B. Clothing and Attachments

http://www.cis.upenn.edu/˜allbeck/clothing.html

C. Ethnicity

http://www.cis.upenn.edu/˜allbeck/ethnicity.html

D. Locomotion

http://www.cis.upenn.edu/˜allbeck/loco.html

E. Body Actions

http://www.cis.upenn.edu/˜allbeck/body.html

F. Forms of Communication

http://www.cis.upenn.edu/˜allbeck/commun.html

G. Facial Actions, Emotions, and Personality

http://www.cis.upenn.edu/˜allbeck/face.html

H. Smiles

http://www.cis.upenn.edu/˜allbeck/smiles.html

References

[1] K. Amaya, A. Bruderlin, and T. Calvert. Emotion from motion. In W. A. Davis and R. Bartels, editors, *Graphics Interface '96*, pages 222–229. Canadian Information Processing Society, Canadian Human-Computer Communications Society, May 1996.

[2] K. Anjyo, Y. Usami, and T. Kurihara. A simple method for extracting the natural beauty of hair. In *SIGGRAPH '92 Proceedings*, volume 26, pages 111–120, July 1992.

[3] N. Badler, M. Hollick, and J. Granieri. Real-time control of a virtual human using minimal sensors. *Presence*, 2(1):82–86, 1993.

[4] N. Badler, C. Phillips, and B. Webber. *Simulating Humans: Computer Graphics Animation and Control.* Oxford University Press, New York, NY, 1993.

[5] J. Bates. The role of emotion in believable agents. *Comm. of the ACM*, 37(7):122–125, 1994.

[6] J. Bates, A. Loyall, and W. Reilly. Integrating reactivity, goals, and emotion in a broad agent. In *Proc. of the 14th Annual Conf. of the Cognitive Science Society*, pages 696–701, Hillsdale, NJ, 1992. Lawrence Erlbaum.

[7] R. Boulic, P. Becheiraz, L. Emering, and D. Thalmann. Integration of motion control techniques for virtual human and avatar real-time animation. In *ACM Symposium on Virtual Reality Software and Technology*, New York, NY, Sept. 1997. ACM Press.

[8] A. Bruderlin and T. W. Calvert. Goal-directed, dynamic animation of human walking. In *SIGGRAPH '89 Proceedings*, volume 23, pages 233–242, July 1989.

[9] A. Bruderlin and T. W. Calvert. Knowledge-driven, interactive animation of human running. In W. A. Davis and R. Bartels, editors, *Graphics Interface '96*, pages 213–221. Canadian Information Processing Society, Canadian Human-Computer Communications Society, May 1996.

[10] A. Bruderlin and L. Williams. Motion signal processing. In *SIGGRAPH '95 Proceedings*, pages 97–104, 1995.

[11] T. Calvert. The challenge of human figure animation. In *Proceedings of Graphics Interface '88*, pages 203–210, June 1988.

[12] T. W. Calvert, J. Chapman, and A. Patla. Aspects of the kinematic simulation of human movement. *IEEE Computer Graphics and Applications*, 2:41–48, Nov. 1982.

[13] T. Capin, H. Noser, D. Thalmann, I. Pandzic, , and N. Magnenat Thalmann. Virtual human representation and communication in VLNET networked virtual environments. *IEEE Computer Graphics and Applications*, 17(2):42–53, 1997.

[14] M. Carignan, Y. Yang, N. M. Thalmann, and D. Thalmann. Dressing animated synthetic actors with complex deformable clothes. In *SIGGRAPH '92 Proceedings*, volume 26, pages 99–104, July 1992.

[15] J. Cassell, C. Pelachaud, N. Badler, M. Steedman, B. Achorn, W. Becket, B. Douville, S. Prevost, and M. Stone. Animated conversation: Rule-based generation of facial expression, gesture and spoken intonation for multiple conversational agents. In *SIGGRAPH '94 Proceedings*, pages 413–420, 1994.

[16] S. Chopra. Where to look? animating the visual attention behavior of human characters. Technical report, Center for Human Modeling and Simulation, University of Pennsylvania, 1998.

[17] M. Courshesnes, P. Volino, and N. M. Thalmann. Versatile and efficient techniques for simulating cloth and other deformable objects. In *SIGGRAPH '95 Proceedings*, pages 137–144, Aug. 1995.

[18] D. DeCarlo and D. Metaxas. The integration of optical flow and deformable models with applications to human face shape and motion estimation. In *Proc. CVPR*, pages 231–238. IEEE Press, 1996.

[19] I. Essa. *Analysis, Interpretation and Synthesis of Facial Expressions*. PhD thesis, Massachusetts Institute of Technology, 1994.

[20] M. Girard and A. Maciejewski. Computational modeling for the computer animation of legged figures. In *SIGGRAPH '85 Proceedings*, pages 263–270, 1985.

[21] J. Gourret, N. Magnenat-Thalmann, and D. Thalmann. Simulation of object and human skin deformations in a grasping task. In *SIGGRAPH '89 Proceedings*, volume 23, pages 21–30, July 1989.

[22] J. Granieri, J. Crabtree, and N. Badler. Off-line production and real-time playback of human figure motion for 3D virtual environments. In *VRAIS Conf.* IEEE Press, 1995.

[23] The VRML Humanoid Animation Working Group, 1997. http://ece.uwaterloo.ca:80/˜h-anim/.

[24] J. K. Hodgins and N. S. Pollard. Adapting simulated behaviors for new characters. In *SIGGRAPH '97 Proceedings*, pages 153–16, Aug. 1997.

[25] T. Hudson, M. Lin, J. Cohen, S. Gottschalk, and D. Manocha. V-collide: Accelerated collision detection for VRML. In *Proceedings of VRML '97*, 1997.

[26] W. L. Johnson and J. Rickel. Steve: An animated pedagogical agent for procedural training in virtual environments. *SIGART Bulletin*, 8(1-4):16–21, 1997.

[27] I. Kakadiaris and D. Metaxas. Model-based estimation of 3D human motion with occlusion based on active multi-viewpoint selection. In *Proc. of the Conf. on Computer Vision and Pattern Recognition*, pages 81–87. IEEE Computer Society, June 1996.

[28] P. Kalra, A. Mangili, N. Magnenat-Thalmann, and D. Thalmann. Smile: A multilayered facial animation system. In T. Kunii, editor, *Modeling in Computer Graphics*. Springer-Verlag, 1991.

[29] H. Ko and N. Badler. Animating human locomotion in real-time using inverse dynamics, balance and comfort control. *IEEE Computer Graphics and Applications*, 16(2):50–59, March 1996.

[30] Y. Koga, K. Kondo, J. Kuffner, and J.-C. Latombe. Planning motions with intentions. In *SIGGRAPH '94 Proceedings*, pages 395–408, 1994.

[31] E. Kokkevis, D. Metaxas, and N. Badler. User-controlled physics-based animation for articulated figures. In *Computer Animation Conf. Proc.*, 1996.

[32] K. Komatsu. Human skin model capable of natural shape variation. *The Visual Computer*, 3(5):265–271, Mar. 1988.

[33] D. Kurlander, T. Skelly, and D. Salesin. Comic chat. In *ACM Computer Graphics, Annual Conf. Series*, pages 225–236, 1996.

[34] J. F. Laszlo, M. van de Panne, and E. Fiume. Limit cycle control and its application to the animation of balancing and walking. In *SIGGRAPH '96 Proceedings*, pages 155–162, Aug. 1996.

[35] Y. Lee, D. Terzopoulos, and K. Waters. Realistic face modeling for animation. In *SIGGRAPH '95 Proceedings*, pages 55–62, Aug. 1995.

[36] P. Maes, T. Darrell, B. Blumberg, and A. Pentland. The ALIVE system: Full-body interaction with autonomous agents. In N. Magnenat-Thalmann and D. Thalmann, editors, *Computer Animation*, pages 11–18. IEEE Computer Society Press, Los Alamitos, CA, 1995.

[37] R. Maiocchi and B. Pernici. Directing an animated scene with autonomous actors. *The Visual Computer*, 6(6):359–371, Dec. 1990.

[38] C. L. Morawetz and T. W. Calvert. Goal-directed human animation of multiple movements. In *Proceedings of Graphics Interface '90*, pages 60–67, May 1990.

[39] M. Nahas, H. Huitric, M. Rious, and J. Domey. Registered 3D-texture imaging. In *Computer Animation '90 (Second workshop on Computer Animation)*, pages 81–91. Springer-Verlag, Apr. 1990.

[40] T. Noma and N. Badler. A virtual human presenter. In *IJCAI '97 Workshop on Animated Interface Agents*, Nagoya, Japan, 1997.

[41] H. Noser, O. Renault, D. Thalmann, and N. M. Thalmann. Navigation for digital actors based on synthetic vision, memory and learning. *Computers and Graphics*, 1995.

[42] I. Pandzic, T. Capin, and N. Magnenat Thalmann. A versatile navigation interface for virtual humans in collaborative virtual environnements. In *ACM Symposium on Virtual Reality Software and Technology*, New York, NY, Sept. 1997. ACM Press.

[43] I. Pandzic, N. M. Thalmann, T. Capin, and D.Thalmann. Virtual life network: A body-centered networked virtual environment. *Presence*, 6(6):676–686, 1997.

[44] F. I. Parke. Computer graphic models for the human face. In *Proc. COMPSAC, The IEEE Computer Society's Third International Computer Software and Applications Conference*, 1979.

[45] F. I. Parke and K. Waters. *Computer Facial Animation*. A K Peters Ltd, 1996.

[46] C. Pelachaud. *Communication and Coarticulation in Facial Animation*. PhD thesis, University of Pennsylvania, 1991.

[47] C. Pelachaud, N. Badler, and M. Steedman. Generating facial expressions for speech. *Cognitive Science*, 20(1):1–46, 1996.

[48] K. Perlin. Real time responsive animation with personality,. *IEEE Transactions on Visualization and Computer Graphics*, 1(1), 1995.

[49] K. Perlin and A. Goldberg. Improv: A system for scripting interactive actors in virtual worlds. In *SIGGRAPH '96 Proceedings*, pages 205–216, 1996.

[50] Poser2, 1997. http://www.fractal.com/products/poser/index.html.

[51] B. Reich. *An architecture for behavioral locomotion*. PhD thesis, CIS, University of Pennsylvania, 1997.

[52] C. Rose, B. Guenter, B. Bodenheimer, and M. Cohen. Efficient generation of motion transitions using spacetime constraints. In *SIGGRAPH '96 Proceedings*, pages 147–154, 1996.

[53] D. Rousseau and B. Hayes-Roth. Personality in synthetic agents. Technical Report KSL-96-21, Stanford Knowledge Systems Laboratory, 1996.

[54] F. Scheepers, R. E. Parent, W. E. Carlson, and S. F. May. Anatomy-based modeling of the human musculature. In *SIGGRAPH '97 Proceedings*, pages 163–172, Aug. 1997.

[55] T. Smith, J. Shi, and N. Badler. JackMOO, a prototype system for natural language avatar control. In *WebSim Proceedings*, San Diego, CA, 1998.

[56] S. Stansfield. Medisim: A prototype VR system for training medical first responders. In *IEEE Virtual Reality Annual International Symposium*, Atlanta, GA, March 1998.

[57] A. J. Stewart and J. F. Cremer. Beyond keyframing: An algorithmic approach to animation. In *Proceedings of Graphics Interface '92*, pages 273–281, May 1992.

[58] D. Wiley and J. Hahn. Interpolation synthesis of articulated figure motion. *IEEE Computer Graphic and Applications*, pages 39–46, November 1997.

[59] J. Wilhelms. VIRYA — A motion control editor for kinematic and dynamic animation. In *Proceedings of Graphics Interface '86*, pages 141–146, May 1986.

[60] J. Wilhelms and A. V. Gelder. Anatomically based modeling. In *SIGGRAPH '97 Proceedings*, pages 173–180, Aug. 1997.